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Random Frequency Function Generation

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The desired signature characteristics of the source generator for use on a long-range acoustic propagation experiment are defined. A programmable frequency function is proposed, consisting of slowly varying frequency undulations whose rate and magnitudes are pseudo-randomly distributed. The power spectral density and other significant properties of the frequency function are derived and displayed in both tabular and graphical form. A method is presented of implementing the random frequency function generator which uses a digital programmable read-only memory as its central element. The function generator is

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20. Abstract (cont.)

simple and reliable in concept and circuit, and should find application in a variety of underwater acoustic experiments.

CONTENTS

RANDOM FREQUENCY FUNCTION GENERATION

INTRODUCTION

As a part of a long-range acoustic propagation correlation experiment, it was necessary to generate a random frequency function to control each source generator as it projects a sinusoidal pressure pattern into the transmission medium. The desired characteristics of the source signal are listed as follows.

1. Essentially a constant-amplitude sinusoidal signal whose instantaneous frequency is slowly undulating about some center frequency in a pseudo-random fashion

2. The maximum peak-to-peak excursion of the instantaneous frequency variations will be a small fraction of the center frequency, and can be preset before each test run.

3. The random frequency undulations are to include a long-term, (relatively) high-amplitude, undulation whose mean period is greater than about 100 s. Superimposed on the long-term undulations will be shorter term frequency undulations whose amplitudes are but a fraction of the peak-to-peak longer term undulations. The minimum period of the shorter term undulations is 5 s.

4. The pseudorandom frequency pattern may be periodic with a period no less than the longest contemplated correlation integration time (viz 640 s). Thus, for statistical samples of the source signal over a time span equal to or less than the cyclic period (640 s), the instantaneous frequency variations of the source may be considered as slowly varying in a pseudorandom fashion about some center frequency.

This report describes the pseudorandom frequency function which will be employed in a long range acoustic propagation correlation experiment. Within the report the synthesized function is presented in tabulated as well as in graphical form. The power spectrum and other significant properties of the frequency function have been computed and tabulated. Finally, a convenient and effective method of implementing the frequency function is described in some detail.

PROGRAMMABLE FREQUENCY FUNCTION

The proposed frequency function for the source projectors consists of a slowly varying undulation whose average period is about 107 s long. Sumperimposed on this long period undulation will be shorter period undulations of lesser magnitude.

Note: Manuscript submitted November 13, 1973.

For convenience, the frequency function is programmable into discrete time periods and amplitude levels. The incremental time period is set at 2.5 s, and the peak-to-peak frequency excursion is divided into 14 steps or 15 discrete levels (plus and minus 7 steps about the mean or center frequency).

The proposed frequency function is presented in Table 1. The table sets forth the sequence of the 15 discrete frequency levels over 256 discrete 2.5-s time increments. The function will repeat after the 256 time increments (10 min, 40 s). Designed in this manner, the frequency function is compatible for digital logic implementation.

Table 1
Proposed Pseudorandom Frequency Function

	$f = f_c$ + nB/14 (Table give values of n)										
Seconds \ Minutes	0	1	2	3	4	5	6	7	8	9	10
0	0	0	1	0	2	-5	5	-5	0	-3	-2
2.5	2	-1	-1	1	4	-4	4	-3	1	-2	-5
5.0	1	-3	2	0	3	-5	6	-1	0	-1	-6
7.5	2	-1	1	-2	4	-7	4	-2	-1	0	-7
10.0	1	-4	3	-1	6	-6	3	-1	-2	1	-6
12.5	3	-3	1	-3	3	-7	2	1	-1	0	-5
15.0	4	-5	3	-4	5	-5	4	0	-2	2	-6
17.5	3	-3	5	-3	7	-3	2	1	0	4	-7
20.0	6	-4	6	-5	6	-2	1	-2	-2	3	-6
22.5	5	-6	5	-6	7	-1	2	1	-1	5	-3
25.0	7	-7	7	-5	5	-3	0	2	-3	6	-4
27.5	5	-6	6	-7	4	-2	1	3	-5	7	-2
30.0	6	-5	5	-6	3	0	-1	5	-4	6	-1
32.5	4	-7	7	-5	5	2	0	3	-6	5	-3
35.0	5	-6	6	-4	3	1	-3	5	-5	4	0
37.5	3	-5	7	-5	4	3	-2	7	-7	5	-1
40.0	4	-4	5	-3	2	4	-4	6	-6	2	0
42.5	2	-5	3	-2	1	5	-2	4	-7	1	2
45.0	3	-3	4	-4	2	3	-3	6	-5	2	1
47.5	1	-2	2	-2	-1	5	-5	5	-4	0	2
50.0	2	-3	1	0	-2	6	-4	4	-6	-2	1
52.5	0	-1	2	1	-4	5	-7	3	-4	0	3
55.0	-1	-2	1	-1	-3	7	-6	4	-3	-3	4
57.5	-2	0	-1	1	-4	6	-4	2	-1	-4	3
60.0	0	1	0	2	-5	5	-5	0	-3	-2	6

A graphical plot of the proposed frequency function is illustrated in Fig. 1. The instantaneous frequency is shown as changing levels in a linear (rather than a stepped) manner. This is probably a more realistic expectation, since the source will not be able to change frequency instantaneously. (In addition, some form of transitional smoothing of the function is intended to be incorporated into the physical implementation of the frequency function generator.) In the illustration, the full period of 640 s is shown split into two 320-s sections for convenience of illustration. The function will repeat after the end of the last time increment.

A second time scale is provided below the function graph in Fig. 1 to illustrate the relation of the seven integration times (10 s, 20 s, etc., to 640 s) to the excursions of the frequency function. In the figure, note that an integration (or sample) time in excess of 80 s will be required (in general) to achieve a representative sample of the source signal statistics. Thus, for the shorter integration times, the information bandwidth of the resulting signal will be less than that achieved for the longer integration times.

SOURCE SIGNAL POWER SPECTRUM

The precise power spectrum for the source signal whose instantaneous frequency is illustrated in Fig. 1 would be quite cumbersome to compute. However, for an essentially sinusoidal signal whose frequency varies slowly with time, a reasonable approximation to the normalized signal power spectrum can be achieved by simply computing the amplitude probability density of the instantaneous frequency function. This procedure should prove adequate for the intended purpose of the frequency function.

Using the suggested approach, we can approximate the power spectral histogram for the proposed frequency function (Fig. 1) as:

$$P_N(f_i) = \frac{1}{\Delta B T}\sum_j \Delta t_{ij} = \frac{N_B}{B}\,\frac{\Delta T}{T}\sum_j \frac{1}{\Delta n_{ij}}$$

$$= \frac{N_B}{N_T B}\sum_j \frac{1}{\Delta n_{ij}} \tag{1}$$

where

$P_N(f_i)$ is the normalized power spectral density in the ith frequency band $\Delta B = B/N_B$
B is the peak-to-peak instantaneous frequency excursion
T = 640 s, the basic period of the pseudorandom sequence
N_B = 14, the total number of frequency steps over the bandwidth extremes B
N_T = 256, the total number of time increments over the total time period T = 640 s
$\Delta B = B/N_B$; $B/14$ is the basic frequency increment
$\Delta T = T/256$; 2.5 s is the basic time increment
Δt_{ij} is the incremental time that the frequency function spends in the ith frequency band for a given jth frequency slide over ΔT time
Δn_{ij} is the number of ΔB steps of the frequency function in sliding through the ith ΔB band in a given jth frequency slide over ΔT time.

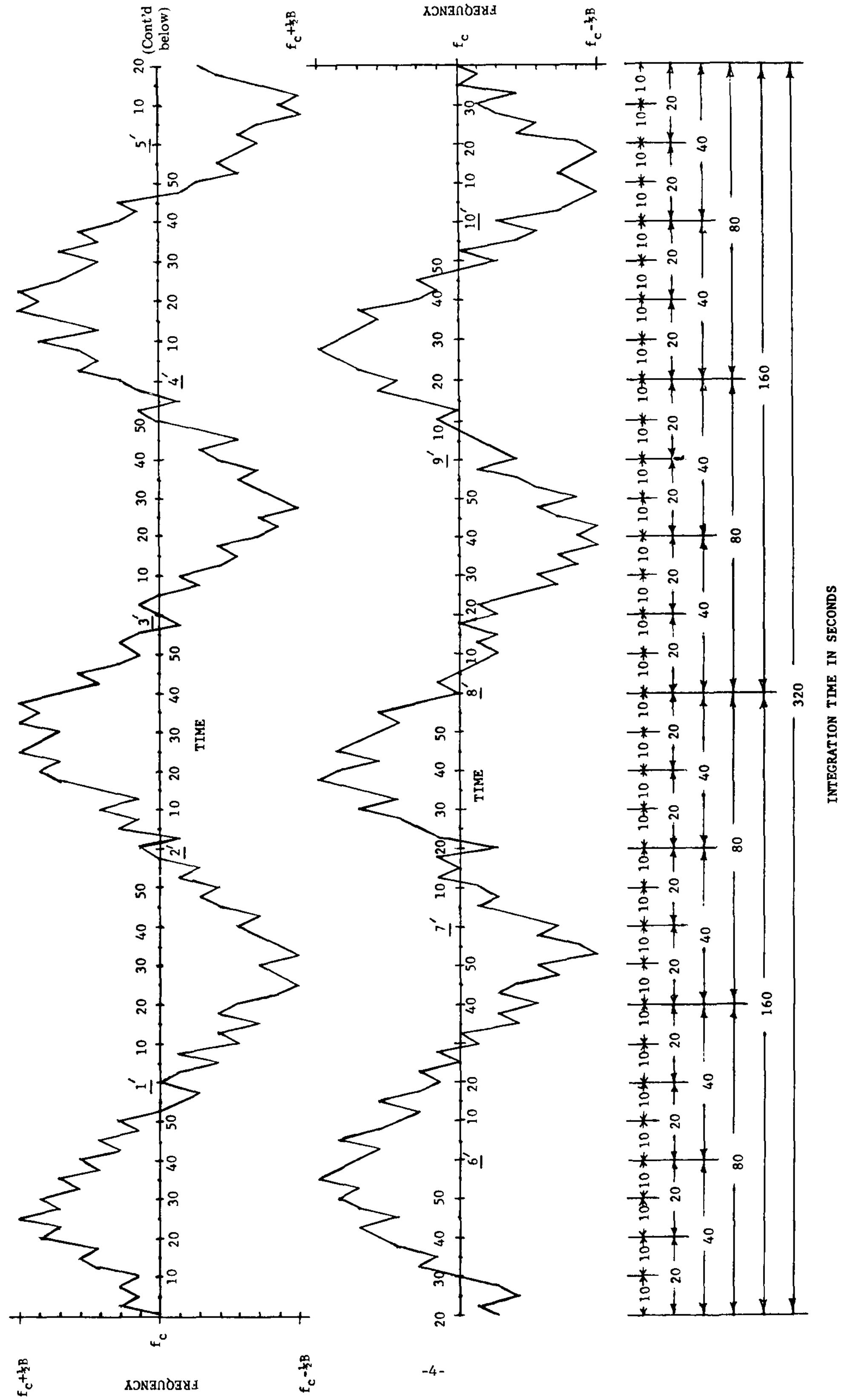

Fig. 1—Source frequency function

The signal power in each frequency band ΔB is, therefore,

$$\Delta B P_N(f_i) = \frac{1}{N_T} \sum_j \frac{1}{\Delta n_{ij}}. \tag{2}$$

It should be evident that

$$\Delta B \sum_i P_N(f_i) = \frac{1}{N_T} \sum_i \sum_j \frac{1}{\Delta n_{ij}} = 1,$$

or

$$\sum_i \sum_j \frac{1}{\Delta n_{ij}} = N_T = 256, \tag{3}$$

and

$$\sum_i \sum_j \Delta t_{ij} = T = 640 \text{ s}. \tag{4}$$

The power spectral histogram for the proposed frequency function (Fig. 1) was computed, using the above relations, and the results are in Table 2. Figure 2 is a graphical representation of the histogram. The figure also depicts a line spectrum for the signal power computed on the basis of purely frequency-shift keying of the source generator (in lieu of the linear frequency translations shown in Fig. 1). In practice, the achievement of a near line spectra will be realized only when $\Delta B \Delta T$ is much greater than unity. This is not anticipated in the subject application, so that Fig. 2a more nearly represents the power spectral density of the proposed source signal. Even here, Fig. 2a, the actual power spectral density can be expected to be a somewhat smoothed and slightly spread rendition of the stepped histogram representation. The calculations and curve, however, do illustrate that the power spectral density of the proposed source function will be reasonably well distributed over the bandwidth B, centered at f_c.

INFORMATION BANDWIDTH OF THE PROPOSED SOURCE FUNCTION

The information bandwidth of the proposed source function can be computed from the relation*

*A. A. Gerlach, *Theory and Applications of Statistical Wave-Period Processing,* Gordon and Breach, Science Publishers Inc., New York, 1970, 1:229-241.

Table 2
Spectral Power of Proposed Source Function

Bin (i)	Power $\Delta BP_N(f_i)$	(Power)^2 $[\Delta BP_N(f_i)]^2$	Moment $i\Delta BP_n(f_i)$
6 to 7	0.0527	0.00278	0.3426
5 to 6	0.0749	0.00561	0.4120
4 to 5	0.0664	0.00441	0.2988
3 to 4	0.0938	0.00880	0.3283
2 to 3	0.0404	0.00163	0.1010
1 to 2	0.0944	0.00891	0.1416
0 to 1	0.0736	0.00542	0.0368
-1 to 0	0.0697	0.00486	-0.0349
-2 to -1	0.0957	0.00916	-0.1436
-3 to -2	0.0710	0.00504	-0.1775
-4 to -3	0.0703	0.00494	-0.2461
-5 to -4	0.0742	0.00551	-0.3339
-6 to -5	0.0592	0.00350	-0.3256
-7 to -6	0.0638	0.00407	-0.4147
14	1.0000	0.07462	-0.0152

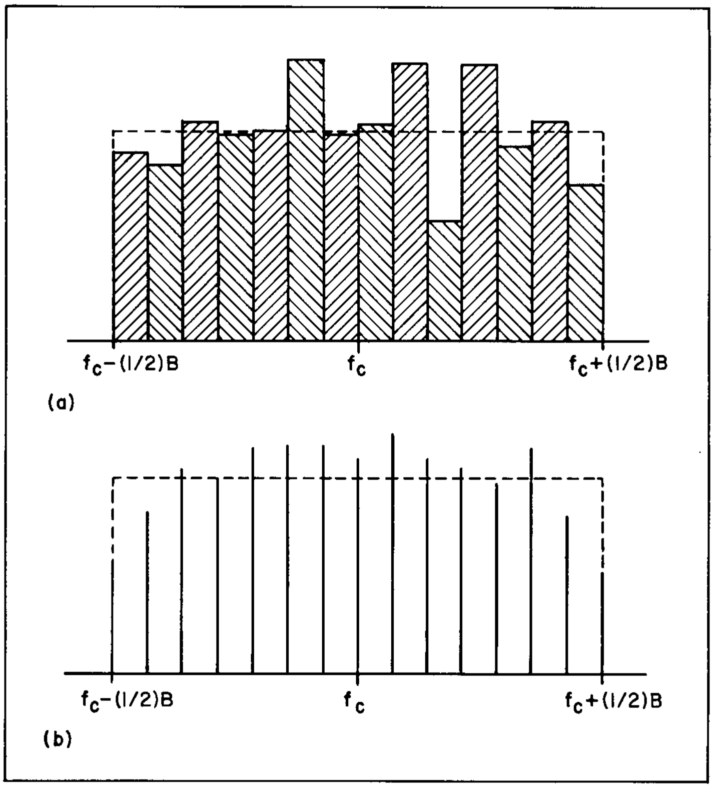

Fig. 2—Source signal power spectrum

$$B_I = \frac{\left[\int_0^{\infty} P_N(f)df\right]^2}{\int_0^{\infty} P_N{}^2(f)df} \approx \frac{\left[\Delta B \sum_i P_N(f_i)\right]^2}{\Delta B \sum_i P_N{}^2(f_i)}$$

$$= \frac{\Delta B}{\sum_i \left[\Delta B P_N(f_i)\right]^2} = \frac{B}{N_B \sum_i \left[\Delta B P_N(f_i)\right]^2} . \tag{5}$$

Using the data in Table 2, one may readily compute the information bandwidth as

$$B_I = B/14(0.07462) = 0.957B. \tag{6}$$

This will be the expected information bandpass to be used for the longer integration times where sufficient samples of the source function are taken to obtain a gross sample representative of the source statistics. Note, by examining Fig. 1, that the relation given in eq. (6) will not be applicable for the shorter integration times where the source function is not sufficiently sampled to obtain a representative gross sample of the source statistics. It should also be evident that the information bandwidth will be variable for integration times less than the full cycle period of 640 s. The degree of variability will be dependent on both the integration time and the location of the integration interval relative to the source function.

Using the pattern depicted in Fig. 1, a table of data was compiled of the expected information bandwidth, and the range of variability of this measure, for the seven integration times under consideration. These data are given in Table 3 for convenient reference.

The data in Table 3 illustrate that the long-term information bandwidth is not achieved until the data sample size (integration time) exceeds about 100 s. This is a result of the long-term frequency undulation (instability) illustrated in Fig. 1.

Finally, Table 4 illustrates the mean or expected information bandwidth as a function of the integration times for various selections of the peak-to-peak frequency deviation B.

INFORMATION CONTENT CONSIDERATIONS

An important output from the long-range acoustic propagation correlation experiment will be the measure of time register (or time delay) between the signal received at two spatially separated sensors. This measure will be achieved by cross-correlating the signals from the two sensors over the indicated integration times. Note, from Fig. 1 and Table 4, that the time register resolution will be negligible for the shorter integration times when the information bandwidth (B in Table 4) is small.

Table 3
Information Bandwidth Statistics

n	T_n (S)	B_{In}/B_I (See Note)		
		Range	Mean	Standard Deviation σ
1	10	0.10 to 0.46	0.22	0.07
2	20	0.15 to 0.55	0.34	0.09
3	40	0.35 to 0.75	0.54	0.11
4	80	0.65 to 1.00	0.85	0.11
5	160	0.90 to 1.00	0.97	0.03
6	320	0.97 to 1.00	0.99	0.01
7	640	—	1.00	0

Note: B_{In} will never be less than $1.5/T_n$ (see A. A. Gerlach, op. cit; Vol. 1, Chap. 3, p. 86, Eq. (3.7.1-12)).

Table 4
Information Bandwidth B_{In} as a Function of B and T_n

T_n (S)	Peak-to-Peak Bandwidth, B(Hz)				
	0.125	0.250	0.500	1.000	2.000
10	0.150	0.150	0.150	0.211	0.422
20	0.075	0.082	0.163	0.326	0.653
40	0.065	0.130	0.259	0.518	1.037
80	0.102	0.204	0.408	0.816	1.632
160	0.116	0.233	0.466	0.931	1.862
320	0.119	0.238	0.475	0.950	1.901
640	0.120	0.240	0.480	0.960	1.920

Since the time scale-factor between the relevant signals will also be a variable, any narrow-bandwidth signal centered at one frequency can be made to match (or overlay) an equally narrow-bandwidth signal centered at a second frequency. Under these circumstances, the envelope covariance coefficient will always be significant for temporal intervals of the signal whose total information content (information-bandwidth, integration-time product) is low. The expected correlation coefficient under these circumstances will approximate

$$\alpha(B_{In}T_n) \approx \frac{\sin \dfrac{\pi B_{In} T_n}{2}}{\dfrac{\pi B_{In} T_n}{2}} . \tag{7}$$

The above relation represents the expected degradation in the envelope covariance coefficient for two uncorrelated narrow-band signals relative to fully coherent signals, when the time-scale factor between the two signals is optimized. As a consequence, the importance of achieving a reasonably large value for the information-bandwidth, integration-time product should be evident. To achieve a significant measure of time register it will be necessary that

$$2 \leqslant B_{In}T_n . \tag{8}$$

For information-bandwidth, integration-time products less than about two, there is little hope of achieving a resolvable measure of time register.

Using the data in Table 4, the resulting information content was computed and is displayed in Table 5. From the table, note that the usefulness of the covariance coefficient will be negligible for values of B and T_n above the broad demarcation line. The

Table 5
Information Content $B_{In}T_n$ as a Function of B and T_n

T_n (S)	Peak-to-Peak Bandwidth, B(Hz)				
	0.125	0.250	0.500	1.000	2.000
10	1.50	1.50	1.50	2.11	4.22
20	1.50	1.64	3.26	6.52	13.06
40	2.60	5.20	10.36	20.72	41.48
80	8.16	16.32	32.64	65.28	130.6
160	18.56	37.28	74.56	149.0	297.9
320	38.08	76.16	152.0	304.0	608.3
640	76.80	153.6	307.2	614.4	1229.0

table demonstrates the necessity for long integration times when the relevant signal information bandwidth is small. A further advantage of the larger information content signals is their ability to be detected and discriminated in an otherwise incoherent background signal environment. The resulting correlated signal enhancement (expressed in decibels) will be directly proportional to 10 times the logarithm of the signal information content.

IMPLEMENTATION OF THE RANDOM FREQUENCY FUNCTION GENERATOR

Since it will be necessary to devise some physical implementation of the proposed random frequency function (illustrated in Fig. 1) to control the source projector, it will be desirable that this implementation be as simple and reliable as possible. Of course, this implementation will need to be compatible with the Mk VI mechanical acoustic projectors contemplated for use in the long-range acoustic propagation correlation experiment.

Basically, the Mk VI projector is a mechanical piston oscillator whose frequency is determined by the rotational speed of a dc electric motor. The speed of the electric motor is, in turn, proportional to a dc control voltage. Thus, the projector is a form of voltage-controlled oscillator whose frequency may be varied by modulating the control voltage to the drive motor.

From the above description, it can be seen that the relevant frequency function can be realized by causing the motor control voltage to be varied in the manner defined by the data from Table 1 and Fig. 1. For the sake of simplicity and reliability, it will be desirable to incrementally change the control voltage level in a programmable digital manner. In this way, the precision and repeatability of the frequency function can be assured. The conversion from digital to analog output, for application to the Mk VI control system, may readily be accomplished using modular D/A converter electronics. This is the approach taken in the implementation scheme to be discussed.

The central control element in the proposed programmable frequency function generator is the P/ROM or Programmable, Read-Only Memory.* This microcircuit element consists of an input binary address and an output data word which may be fixed, or "burned-into," the memory for each input address. The process of fixing or "burning-in" the data word is accomplished only once (in a preprogramming operation). After this, the P/ROM acts simply as a read-only memory, with the data words in memory repeating for the same addresses. Thus, by incrementing the input address through its entire sequence, the corresponding output may be made to follow any given pattern, such as the one shown in Table 1. For the subject application, a P/ROM with an 8-bit input address and a 4-bit output word is required. The programmed relation between the output word and the input address is listed in Table 6.

The proposed method of utilizing the P/ROM concept in the frequency function generator is illustrated in Fig. 3. The basic elements of the Mark VI control electronics are illustrated in the top part of the diagram, while the variable frequency function control is shown in the lower portion of the diagram. The diagram depicts convenient operational and calibration controls.

Basically, the frequency control voltage is the sum of the two voltages coming from the SET CENTER FREQ. potentiometer and the output of the frequency Function Generator, through the SW-1 (COMEX-FINEX) switch at the top of the diagram. The tachometer feedback voltage is used to null-balance the control voltage for purposes of achieving a highly stable output frequency for any control voltage setting. The variable portion of the control voltage is achieved at the output of the D/A converter. This output reflects the D/A conversion of the digital P/ROM output word as the 8-BIT address register is sequenced through its 256-bit address via the clock generator. The level of the D/A converter output can be set, through SW-4, to reflect the five peak-to-peak frequency shifts B given in Table 4. The digitally stepped output, at this point, is also smoothed through the operational amplifier integrator circuit before combining with the other control voltages in the Mk VI Electronic Control portion of the circuit.

*The basic idea of using the P/ROM in the subject application was contributed by Mr. Caldwell McCoy, Jr. of NRL.

Table 6
P/ROM Coding Table

ADDRESS		WORD	
000	0 0 0 0 0 0 0 0	0 0 0	0
001	0 0 0 0 0 0 0 1	+ 0 1 0	2
002	0 0 0 0 0 0 1 0	+ 0 0 1	1
003	0 0 0 0 0 0 1 1	+ 0 1 0	2
004	0 0 0 0 0 1 0 0	+ 0 0 1	1
005	0 0 0 0 0 1 0 1	+ 0 1 1	3
006	0 0 0 0 0 1 1 0	+ 1 0 0	4
007	0 0 0 0 0 1 1 1	+ 0 1 1	3
008	0 0 0 0 1 0 0 0	+ 1 1 0	6
009	0 0 0 0 1 0 0 1	+ 1 0 1	5
010	0 0 0 0 1 0 1 0	+ 1 1 1	7
011	0 0 0 0 1 0 1 1	+ 1 0 1	5
012	0 0 0 0 1 1 0 0	+ 1 1 0	6
013	0 0 0 0 1 1 0 1	+ 1 0 0	4
014	0 0 0 0 1 1 1 0	+ 1 0 1	5
015	0 0 0 0 1 1 1 1	+ 0 1 1	3
016	0 0 0 1 0 0 0 0	+ 1 0 0	4
017	0 0 0 1 0 0 0 1	+ 0 1 0	2
018	0 0 0 1 0 0 1 0	+ 0 1 1	3
019	0 0 0 1 0 0 1 1	+ 0 0 1	1
020	0 0 0 1 0 1 0 0	+ 0 1 0	2
021	0 0 0 1 0 1 0 1	0 0 0	0
022	0 0 0 1 0 1 1 0	- 0 0 1	-1
023	0 0 0 1 0 1 1 1	- 0 1 0	-2
024	0 0 0 1 1 0 0 0	0 0 0	0
025	0 0 0 1 1 0 0 1	- 0 0 1	-1
026	0 0 0 1 1 0 1 0	- 0 1 1	-3
027	0 0 0 1 1 0 1 1	- 0 0 1	-1
028	0 0 0 1 1 1 0 0	- 1 0 0	-4
029	0 0 0 1 1 1 0 1	- 0 1 1	-3
030	0 0 0 1 1 1 1 0	- 1 0 1	-5
031	0 0 0 1 1 1 1 1	- 0 1 1	-3
032	0 0 1 0 0 0 0 0	- 1 0 0	-4
033	0 0 1 0 0 0 0 1	- 1 1 0	-6
034	0 0 1 0 0 0 1 0	- 1 1 1	-7
035	0 0 1 0 0 0 1 1	- 1 1 0	-6
036	0 0 1 0 0 1 0 0	- 1 0 1	-5
037	0 0 1 0 0 1 0 1	- 1 1 1	-7
038	0 0 1 0 0 1 1 0	- 1 1 0	-6
039	0 0 1 0 0 1 1 1	- 1 0 1	-5
040	0 0 1 0 1 0 0 0	- 1 0 0	-4
041	0 0 1 0 1 0 0 1	- 1 0 1	-5
042	0 0 1 0 1 0 1 0	- 0 1 1	-3
043	0 0 1 0 1 0 1 1	- 0 1 0	-2
044	0 0 1 0 1 1 0 0	- 0 1 1	-3
045	0 0 1 0 1 1 0 1	- 0 0 1	-1
046	0 0 1 0 1 1 1 0	- 0 1 0	-2
047	0 0 1 0 1 1 1 1	0 0 0	0
048	0 0 1 1 0 0 0 0	+ 0 0 1	1
049	0 0 1 1 0 0 0 1	- 0 0 1	-1
050	0 0 1 1 0 0 1 0	+ 0 1 0	2
051	0 0 1 1 0 0 1 1	+ 0 0 1	1
052	0 0 1 1 0 1 0 0	+ 0 1 1	3
053	0 0 1 1 0 1 0 1	+ 0 0 1	1
054	0 0 1 1 0 1 1 0	+ 0 1 1	3
055	0 0 1 1 0 1 1 1	+ 1 0 1	5
056	0 0 1 1 1 0 0 0	+ 1 1 0	6
057	0 0 1 1 1 0 0 1	+ 1 0 1	5
058	0 0 1 1 1 0 1 0	+ 1 1 1	7
059	0 0 1 1 1 0 1 1	+ 1 1 0	6
060	0 0 1 1 1 1 0 0	+ 1 0 1	5
061	0 0 1 1 1 1 0 1	+ 1 1 1	7
062	0 0 1 1 1 1 1 0	+ 1 1 0	6
063	0 0 1 1 1 1 1 1	+ 1 1 1	7

(table continues)

Table 6
P/ROM Coding Table (Continued)

ADDRESS		WORD		ADDRESS		WORD	
064	0 1 0 0 0 0 0 0	+ 1 0 1	5	096	0 1 1 0 0 0 0 0	+ 0 1 0	2
065	0 1 0 0 0 0 0 1	+ 0 1 1	3	097	0 1 1 0 0 0 0 1	+ 1 0 0	4
066	0 1 0 0 0 0 1 0	+ 1 0 0	4	098	0 1 1 0 0 0 1 0	+ 0 1 1	3
067	0 1 0 0 0 0 1 1	+ 0 1 0	2	099	0 1 1 0 0 0 1 1	+ 1 0 0	4
068	0 1 0 0 0 1 0 0	+ 0 0 1	1	100	0 1 1 0 0 1 0 0	+ 1 1 0	6
069	0 1 0 0 0 1 0 1	+ 0 1 0	2	101	0 1 1 0 0 1 0 1	+ 0 1 1	3
070	0 1 0 0 0 1 1 0	+ 0 0 1	1	102	0 1 1 0 0 1 1 0	+ 1 0 1	5
071	0 1 0 0 0 1 1 1	- 0 0 1	-1	103	0 1 1 0 0 1 1 1	+ 1 1 1	7
072	0 1 0 0 1 0 0 0	0 0 0	0	104	0 1 1 0 1 0 0 0	+ 1 1 0	6
073	0 1 0 0 1 0 0 1	+ 0 0 1	1	105	0 1 1 0 1 0 0 1	+ 1 1 1	7
074	0 1 0 0 1 0 1 0	0 0 0	0	106	0 1 1 0 1 0 1 0	+ 1 0 1	5
075	0 1 0 0 1 0 1 1	- 0 1 0	-2	107	0 1 1 0 1 0 1 1	+ 1 0 0	4
076	0 1 0 0 1 1 0 0	- 0 0 1	-1	108	0 1 1 0 1 1 0 0	+ 0 1 1	3
077	0 1 0 0 1 1 0 1	- 0 1 1	-3	109	0 1 1 0 1 1 0 1	+ 1 0 1	5
078	0 1 0 0 1 1 1 0	- 1 0 0	-4	110	0 1 1 0 1 1 1 0	+ 0 1 1	3
079	0 1 0 0 1 1 1 1	- 0 1 1	-3	111	0 1 1 0 1 1 1 1	+ 1 0 0	4
080	0 1 0 1 0 0 0 0	- 1 0 1	-5	112	0 1 1 1 0 0 0 0	+ 0 1 0	2
081	0 1 0 1 0 0 0 1	- 1 1 0	-6	113	0 1 1 1 0 0 0 1	+ 0 0 1	1
082	0 1 0 1 0 0 1 0	- 1 0 1	-5	114	0 1 1 1 0 0 1 0	+ 0 1 0	2
083	0 1 0 1 0 0 1 1	- 1 1 1	-7	115	0 1 1 1 0 0 1 1	- 0 0 1	-1
084	0 1 0 1 0 1 0 0	- 1 1 0	-6	116	0 1 1 1 0 1 0 0	- 0 1 0	-2
085	0 1 0 1 0 1 0 1	- 1 0 1	-5	117	0 1 1 1 0 1 0 1	- 1 0 0	-4
086	0 1 0 1 0 1 1 0	- 1 0 0	-4	118	0 1 1 1 0 1 1 0	- 0 1 1	-3
087	0 1 0 1 0 1 1 1	- 1 0 1	-5	119	0 1 1 1 0 1 1 1	- 1 0 0	-4
088	0 1 0 1 1 0 0 0	- 0 1 1	-3	120	0 1 1 1 1 0 0 0	- 1 0 1	-5
089	0 1 0 1 1 0 0 1	- 0 1 0	-2	121	0 1 1 1 1 0 0 1	- 1 0 0	-4
090	0 1 0 1 1 0 1 0	- 1 0 0	-4	122	0 1 1 1 1 0 1 0	- 1 0 1	-5
091	0 1 0 1 1 0 1 1	- 0 1 0	-2	123	0 1 1 1 1 0 1 1	- 1 1 1	-7
092	0 1 0 1 1 1 0 0	0 0 0	0	124	0 1 1 1 1 1 0 0	- 1 1 0	-6
093	0 1 0 1 1 1 0 1	+ 0 0 1	1	125	0 1 1 1 1 1 0 1	- 1 1 1	-7
094	0 1 0 1 1 1 1 0	- 0 0 1	-1	126	0 1 1 1 1 1 1 0	- 1 0 1	-5
095	0 1 0 1 1 1 1 1	+ 0 0 1	1	127	0 1 1 1 1 1 1 1	- 0 1 1	-3

(table continues)

Table 6
P/ROM Coding Table (Continued)

ADDRESS		WORD		ADDRESS		WORD	
128	1 0 0 0 0 0 0 0	- 0 1 0	-2	160	1 0 1 0 0 0 0 0	- 1 0 0	-4
129	1 0 0 0 0 0 0 1	- 0 0 1	-1	161	1 0 1 0 0 0 0 1	- 0 1 0	-2
130	1 0 0 0 0 0 1 0	- 0 1 1	-3	162	1 0 1 0 0 0 1 0	- 0 1 1	-3
131	1 0 0 0 0 0 1 1	- 0 1 0	-2	163	1 0 1 0 0 0 1 1	- 1 0 1	-5
132	1 0 0 0 0 1 0 0	0 0 0	0	164	1 0 1 0 0 1 0 0	- 1 0 0	-4
133	1 0 0 0 0 1 0 1	+ 0 1 0	2	165	1 0 1 0 0 1 0 1	- 1 1 1	-7
134	1 0 0 0 0 1 1 0	+ 0 0 1	1	166	1 0 1 0 0 1 1 0	- 1 1 0	-6
135	1 0 0 0 0 1 1 1	+ 0 1 1	3	167	1 0 1 0 0 1 1 1	- 1 0 0	-4
136	1 0 0 0 1 0 0 0	+ 1 0 0	4	168	1 0 1 0 1 0 0 0	- 1 0 1	-5
137	1 0 0 0 1 0 0 1	+ 1 0 1	5	169	1 0 1 0 1 0 0 1	- 0 1 1	-3
138	1 0 0 0 1 0 1 0	+ 0 1 1	3	170	1 0 1 0 1 0 1 0	- 0 0 1	-1
139	1 0 0 0 1 0 1 1	+ 1 0 1	5	171	1 0 1 0 1 0 1 1	- 0 1 0	-2
140	1 0 0 0 1 1 0 0	+ 1 1 0	6	172	1 0 1 0 1 1 0 0	- 0 0 1	-1
141	1 0 0 0 1 1 0 1	+ 1 0 1	5	173	1 0 1 0 1 1 0 1	+ 0 0 1	1
142	1 0 0 0 1 1 1 0	+ 1 1 1	7	174	1 0 1 0 1 1 1 0	0 0 0	0
143	1 0 0 0 1 1 1 1	+ 1 1 0	6	175	1 0 1 0 1 1 1 1	+ 0 0 1	1
144	1 0 0 1 0 0 0 0	+ 1 0 1	5	176	1 0 1 1 0 0 0 0	- 0 1 0	-2
145	1 0 0 1 0 0 0 1	+ 1 0 0	4	177	1 0 1 1 0 0 0 1	+ 0 0 1	1
146	1 0 0 1 0 0 1 0	+ 1 1 0	6	178	1 0 1 1 0 0 1 0	+ 0 1 0	2
147	1 0 0 1 0 0 1 1	+ 1 0 0	4	179	1 0 1 1 0 0 1 1	+ 0 1 1	3
148	1 0 0 1 0 1 0 0	+ 0 1 1	3	180	1 0 1 1 0 1 0 0	+ 1 0 1	5
149	1 0 0 1 0 1 0 1	+ 0 1 0	2	181	1 0 1 1 0 1 0 1	+ 0 1 1	3
150	1 0 0 1 0 1 1 0	+ 1 0 0	4	182	1 0 1 1 0 1 1 0	+ 1 0 1	5
151	1 0 0 1 0 1 1 1	+ 0 1 0	2	183	1 0 1 1 0 1 1 1	+ 1 1 1	7
152	1 0 0 1 1 0 0 0	+ 0 0 1	1	184	1 0 1 1 1 0 0 0	+ 1 1 0	6
153	1 0 0 1 1 0 0 1	+ 0 1 0	2	185	1 0 1 1 1 0 0 1	+ 1 0 0	4
154	1 0 0 1 1 0 1 0	0 0 0	0	186	1 0 1 1 1 0 1 0	+ 1 1 0	6
155	1 0 0 1 1 0 1 1	+ 0 0 1	1	187	1 0 1 1 1 0 1 1	+ 1 0 1	5
156	1 0 0 1 1 1 0 0	- 0 0 1	-1	188	1 0 1 1 1 1 0 0	+ 1 0 0	4
157	1 0 0 1 1 1 0 1	0 0 0	0	189	1 0 1 1 1 1 0 1	+ 0 1 1	3
158	1 0 0 1 1 1 1 0	- 0 1 1	-3	190	1 0 1 1 1 1 1 0	+ 1 0 0	4
159	1 0 0 1 1 1 1 1	- 0 1 0	-2	191	1 0 1 1 1 1 1 1	+ 0 1 0	2

(table continues)

Table 6
P/ROM Coding Table (Continued)

ADDRESS		WORD		ADDRESS		WORD	
192	1 1 0 0 0 0 0 0	0 0 0	0	224	1 1 1 0 0 0 0 0	+ 0 1 1	3
193	1 1 0 0 0 0 0 1	+ 0 0 1	1	225	1 1 1 0 0 0 0 1	+ 1 0 1	5
194	1 1 0 0 0 0 1 0	0 0 0	0	226	1 1 1 0 0 0 1 0	+ 1 1 0	6
195	1 1 0 0 0 0 1 1	- 0 0 1	-1	227	1 1 1 0 0 0 1 1	+ 1 1 1	7
196	1 1 0 0 0 1 0 0	- 0 1 0	-2	228	1 1 1 0 0 1 0 0	+ 1 1 0	6
197	1 1 0 0 0 1 0 1	- 0 0 1	-1	229	1 1 1 0 0 1 0 1	+ 1 0 1	5
198	1 1 0 0 0 1 1 0	- 0 1 0	-2	230	1 1 1 0 0 1 1 0	+ 1 0 0	4
199	1 1 0 0 0 1 1 1	0 0 0	0	231	1 1 1 0 0 1 1 1	+ 1 0 1	5
200	1 1 0 0 1 0 0 0	- 0 1 0	-2	232	1 1 1 0 1 0 0 0	+ 0 1 0	2
201	1 1 0 0 1 0 0 1	- 0 0 1	-1	233	1 1 1 0 1 0 0 1	+ 0 0 1	1
202	1 1 0 0 1 0 1 0	- 0 1 1	-3	234	1 1 1 0 1 0 1 0	+ 0 1 0	2
203	1 1 0 0 1 0 1 1	- 1 0 1	-5	235	1 1 1 0 1 0 1 1	0 0 0	0
204	1 1 0 0 1 1 0 0	- 1 0 0	-4	236	1 1 1 0 1 1 0 0	- 0 1 0	-2
205	1 1 0 0 1 1 0 1	- 1 1 0	-6	237	1 1 1 0 1 1 0 1	0 0 0	0
206	1 1 0 0 1 1 1 0	- 1 0 1	-5	238	1 1 1 0 1 1 1 0	- 0 1 1	-3
207	1 1 0 0 1 1 1 1	- 1 1 1	-7	239	1 1 1 0 1 1 1 1	- 1 0 0	-4
208	1 1 0 1 0 0 0 0	- 1 1 0	-6	240	1 1 1 1 0 0 0 0	- 0 1 0	-2
209	1 1 0 1 0 0 0 1	- 1 1 1	-7	241	1 1 1 1 0 0 0 1	- 1 0 1	-5
210	1 1 0 1 0 0 1 0	- 1 0 1	-5	242	1 1 1 1 0 0 1 0	- 1 1 0	-6
211	1 1 0 1 0 0 1 1	- 1 0 0	-4	243	1 1 1 1 0 0 1 1	- 1 1 1	-7
212	1 1 0 1 0 1 0 0	- 1 1 0	-6	244	1 1 1 1 0 1 0 0	- 1 1 0	-6
213	1 1 0 1 0 1 0 1	- 1 0 0	-4	245	1 1 1 1 0 1 0 1	- 1 0 1	-5
214	1 1 0 1 0 1 1 0	- 0 1 1	-3	246	1 1 1 1 0 1 1 0	- 1 1 0	-6
215	1 1 0 1 0 1 1 1	- 0 0 1	-1	247	1 1 1 1 0 1 1 1	- 1 1 1	-7
216	1 1 0 1 1 0 0 0	- 0 1 1	-3	248	1 1 1 1 1 0 0 0	- 1 1 0	-6
217	1 1 0 1 1 0 0 1	- 0 1 0	-2	249	1 1 1 1 1 0 0 1	- 0 1 1	-3
218	1 1 0 1 1 0 1 0	- 0 0 1	-1	250	1 1 1 1 1 0 1 0	- 1 0 0	-4
219	1 1 0 1 1 0 1 1	0 0 0	0	251	1 1 1 1 1 0 1 1	- 0 1 0	-2
220	1 1 0 1 1 1 0 0	+ 0 0 1	1	252	1 1 1 1 1 1 0 0	- 0 0 1	-1
221	1 1 0 1 1 1 0 1	0 0 0	0	253	1 1 1 1 1 1 0 1	- 0 1 1	-3
222	1 1 0 1 1 1 1 0	+ 0 1 0	2	254	1 1 1 1 1 1 1 0	0 0 0	0
223	1 1 0 1 1 1 1 1	+ 1 0 0	4	255	1 1 1 1 1 1 1 1	- 0 0 1	-1

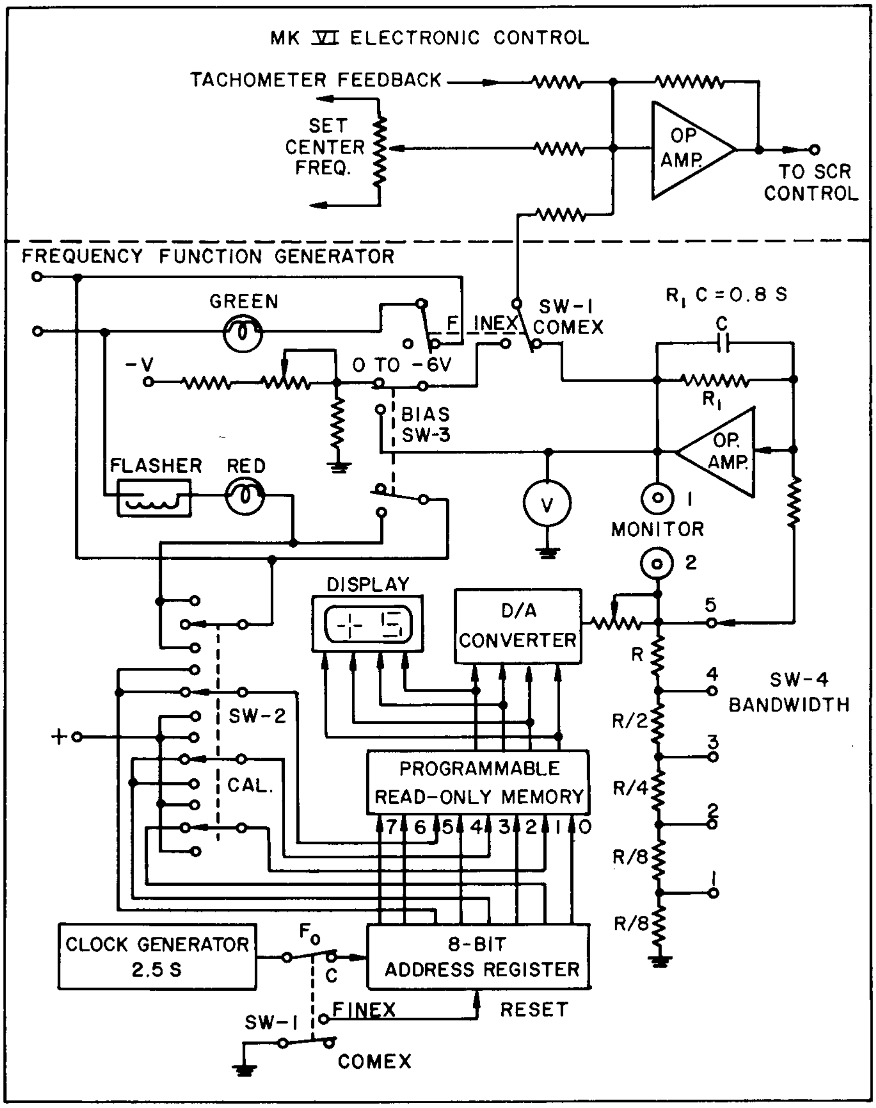

Fig. 3—Frequency function generator

Prior to COMEX and after FINEX of a test run (when the COMEX-FINEX switch, SW-1, is in the FINEX position), the control voltage from the Frequency Function Generator, is connected to a negative bias voltage to offset the center frequency to a position outside of the normal bandwidth range. In this way, convenient COMEX and FINEX indications may be achieved without turning off the Mk VI projector. Also, in the FINEX position of SW-1, the clock generator is disengaged and the address register is reset to zero.

The proposed circuit includes a calibrate switch, SW-2. This switch sets the P/ROM address to values which give the peak-to-peak output words (±7) for convenience in pretest calibrations. Switch SW-3 may be employed to remove the bias voltage and include the Mk VI projector in the case of full calibration. Trim potentiometers are included for use in the calibration.

Additional features of the programmable frequency function generator include (a) a flashing red warning light to alert the operator when the unit is not in the proper test mode, (b) a digital code word display and voltmeter for monitoring the operation during a test run, and (c) two MONITOR connectors to use for recording the programmed output if desired.

A suggested front panel arrangement of the displays and controls is illustrated in Fig. 4.

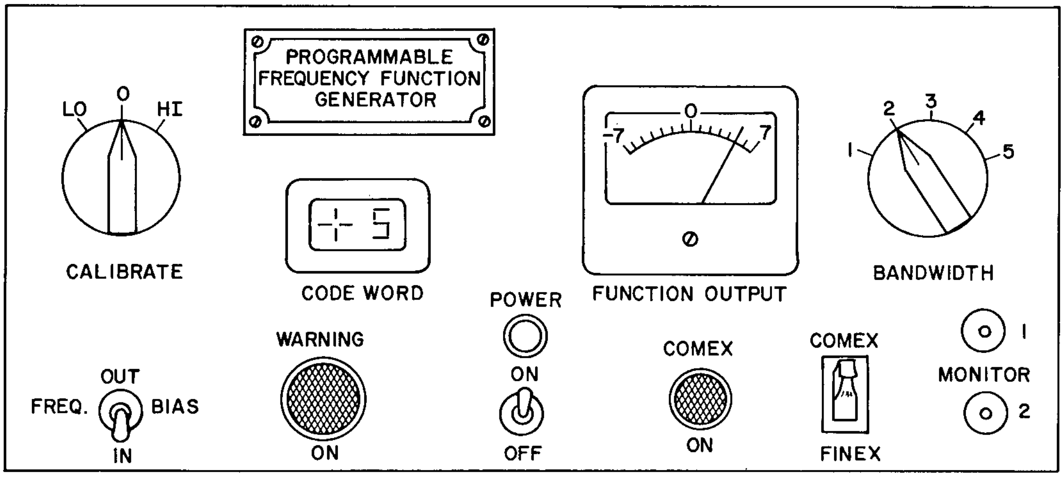

Fig. 4—Proposed panel layout for frequency function generator